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Engineering Design File

Risk Assessment for the Residual Radiological Contamination at the BORAX-I Reactor Burial Site, CERCLA Site BORAX-02, OU 6-01

Prepared for:
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4. Summary:

An assessment of the Boiling Water Reactor Experiment (BORAX)-I site was performed to evaluate the nature and extent of the soil contamination that remains outside the engineered cap at the site. Upon review of the data, and based on the heterogeneous nature of the contaminant distribution, the 1998 Global Positioning Radiometric Scanner (GPRS) survey data were selected for use in the risk assessment. The Cs-137 data were corrected for the shielding provided by the 15-cm (6-in.) gravel layer and for radioactive decay to May 2002. Historical data were used to establish ratios of Sr-90 and U-235 to Cs-137 in order to estimate the concentrations of Sr-90 and U-235.

An assessment was performed based on the corrected 1998 GPRS survey data using two methods, namely, RESidual RADioactivity (RESRAD) modeling and the standard baseline risk assessment methodology as presented in the Operable Unit (OU) 10-04 comprehensive remedial investigation/feasibility study (DOE-ID 2001). The RESRAD modeling indicated that soil concentrations of Cs-137 at Areas 1 and 2 exceeded acceptable risk levels to the current worker, and Area1 exceeded acceptable risk levels to the future worker and future resident. Additionally, when the entire area of contamination was considered as a whole, the soil concentrations of Cs-137 exceeded acceptable risk levels based on a current worker scenario. However, the occupational dose based on the RESRAD modeling is within acceptable levels based on the *INEEL Radiological Control Manual* (INEEL 2000a).

Using the standard baseline risk assessment methodology, neither the nine individual areas nor the entire area of contamination presented unacceptable risks to the current and future worker or the future resident. This approach is considered less conservative than the RESRAD modeling.

The results of this assessment concluded that the dose to both current and future receptors is acceptable at this site, although two areas of contamination may exceed risk-based levels (1E-04). However, this risk is considered acceptable based on the uncertainties associated with the analysis, combined with the understanding that the residual Cs-137 activity at the site will decay to acceptable risk levels in approximately 130 years. Until that time, the proposed institutional controls and land use restrictions listed in the draft record of decision for OUs 6-05 and 10-04 (DOE-ID 2002) will remain in place at the site and will be adequately protective of human receptors under the scenarios assessed.

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(See instructions for definitions of terms and significance of signatures.)

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CONTENTS

FIGURES

TABLES

ACRONYMS

ARA	Auxiliary Reactor Area
BORAX	Boiling Water Reactor Experiment
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
COC	contaminant of concern
DOE	Department of Energy
DOE-ID	Department of Energy Idaho Operations Office
EDF	Engineering Design File
EPA	Environmental Protection Agency
EPC	exposure point concentration
GPRS	Global Positioning Radiometric Scanner
GPS	global positioning system
INEEL	Idaho National Engineering and Environmental Laboratory
INEL	Idaho National Engineering Laboratory
NEPC	new exposure point concentration
OU	operable unit
RESL	Radiological and Environmental Sciences Laboratory
RESRAD	RESidual RADioactivity
RI/FS	remedial investigation/feasibility study
RML	Radiation Measurements Laboratory
SL-1	Stationary Low-Power Reactor No. 1

1. INTRODUCTION

The Boiling Water Reactor Experiment (BORAX)-I was a small, remotely operated water-cooled and -moderated reactor that was operated and tested during 1953 and 1954. The final test of the reactor was the intentional destruction of the reactor, resulting in a release of radiological contamination to the surrounding soils. Approximately 7,800 m^2 (83,960 ft^2) of land to the south of the reactor was contaminated with fuel fragments and radiologically contaminated objects from the reactor, as shown by numerous site surveys after the reactor excursion. Approximately one year after the excursion, the test site was cleaned up to the extent practical, the reactor pit was backfilled, and the entire area was covered with a minimum of 15 cm (6 in.) of sand and gravel. In 1996, a Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) remedial action was conducted to mitigate the excess risk associated with Cs-137, Sr-90, and U-235 contamination in surface soils (Department of Energy Idaho Operations Office [DOE-ID] 1997a).

Subsequent to the remedial action, and in accordance with the Operable Unit (OU) 5-05/6-01 operations and maintenance plan (Idaho National Engineering Laboratory [INEL] 1997), the site has been surveyed annually for radioactivity. The annual radiological survey performed in 1998 (Environmental Protection Agency [EPA] 2001) included use of the Idaho National Engineering and Environmental Laboratory (INEEL) Global Positioning Radiometric Scanner (GPRS). The GPRS survey identified the area of elevated activity outside the engineered cap at the BORAX-I burial ground. Although this area of elevated activity was identified in historical surveys (and in annual surveys subsequent to the remedial action), it was not included in the remedial action at the BORAX-I site. The residual contamination remaining at the BORAX-02 site has been assessed previously and was determined not to present an unacceptable risk (DOE-ID 2001); however, the concern is that the soil sampling data used in that CERCLA risk assessment were not representative due to the fact that the contamination is heterogeneously distributed at the site.

This engineering design file (EDF) will briefly discuss the operational history of the BORAX-I reactor and the 1998 GPRS survey of the BORAX-I site. Finally, an analysis based on the 1998 GPRS survey data is presented using modeled soil concentrations to calculate risk with the Track 2 guidance based on EPA guidance for CERCLA (DOE-ID 1994) and RESidual RADioactivity (RESRAD) to evaluate dose and risk using the standard EPA guidance.

2. SITE BACKGROUND

2.1 BORAX-I Reactor Operation

BORAX-I was a small, water-cooled and -moderated experimental reactor used for testing boiling water reactor technology. The reactor was operated remotely from a trailer located approximately 800 m (0.5 mi) southeast of the reactor, near the Experimental Breeder Reactor I entrance. The reactor core consisted of a number of fuel elements secured at the bottom by a supporting grid and at the top by a removable cover grid. The core grid could accommodate 36 fuel elements, but criticality could be reached with 26 fuel elements (Dietrich and Layman 1954). A maximum of 30 elements was used in the experimental programs.

Experimental excursions were conducted at BORAX-I starting in 1953. The excursions, routinely performed within periods as short as 5 ms, induced violent ejections of water from the reactor, and water was thrown out of the reactor tank to a height of approximately 9 m (30 ft). The design mission of the reactor ended in 1954, and the decision was made to make one final excursion that would result in the destruction of the reactor.

The final experiment with the BORAX-I reactor was performed on July 22, 1954. The reactor core contained 30 fuel elements, resulting in a total reactor core U-235 content of approximately 4.2 kg (Dietrich 1954). The final test excursion liberated an estimated 135 MW-seconds of energy. The resulting explosion tore the reactor vessel completely apart and removed all but the dished bottom from the shield tank. The excursion contaminated approximately 7,800 m^2 (84,000 ft^2) of ground, in a strip approximately 61 m (200 ft) wide and 128 m (420 ft) long, extending south-southeast of the reactor.

2.2 Site Cleanup Activities

An investigation immediately after the excursion revealed that debris was scattered over the area to the south-southeast of the reactor. Numerous metal fragments, including pieces of fuel elements, were recovered during the initial site cleanup; however, removal of these pieces did not significantly reduce the general radiation levels in the area. As a result, the contaminated area of approximately 7,800 m^2 (84,000 ft^2) was covered with clean gravel to a nominal depth of 15 cm (6 in.), reducing the exposure rate to less than 5 mrem/hr.

Approximately one year after the final excursion, the bottom half of the shield tank was filled with the remaining debris, activated metal scrap, and unrecovered fuel residue; lead shielding from the reactor may also be present. The area was backfilled with clean soil, and a layer of gravel was placed over and around the reactor burial site for added shielding from the buried materials (Smith 1980).

Subsequent to the initial cleanup and burial activities, the site was remediated in 1996 under CERCLA. Remediation included consolidation of radiologically contaminated surface soils on top of the burial site. A human-intrusion barrier (riprap) was placed over the consolidated contaminated soils. A chain-link fence, warning signs, and granite monuments were placed around the newly installed cover to deter/prevent human intrusion (DOE-ID 1997a). Annual inspections, including radiological surveys, are ongoing at the BORAX-I burial site.

3. PREVIOUS INVESTIGATIONS

As stated previously, numerous investigations and surveys have been performed at the BORAX-I site in attempts to delineate the nature and extent of contamination. Brief discussions of the investigations and surveys are provided in Appendix A. Although they were not submitted to the rigorous data validation procedures currently required for environmental investigations, the data collected in previous studies consistently indicated that contamination was present at the site and that the contamination was primarily Cs-137, Sr-90, and U-235 in the surface and subsurface soils. For the purposes of this assessment, the data from the 1998 GPRS survey at BORAX-02 were selected as the most comprehensive and representative for estimating risk. The following section discusses the 1998 GPRS survey data.

3.1 INEEL Global Positioning Radiometric Scanner Survey: 1998

As part of the annual site inspection and survey in 1998, a drive-over radiological survey was conducted using the INEEL GPRS. The INEEL GPRS is a mobile field survey system designed to rapidly characterize the areal extent of gamma-emitting radionuclide contamination of surficial soils. The GPRS consists of two large-area plastic scintillation detectors mounted on the front of a Humvee all-terrain vehicle that is equipped with global positioning system (GPS) navigation instruments. The detector height is fixed at 1 m (3.3 ft). At this height, and at a speed of 8 km/hr (5 mph), the detector has a rectangular field of view measuring approximately 16.5 m (54 ft) wide by 9.9 m (32 ft) long. The GPRS uses an on-board computer to integrate the radiological data (counts per second) with the GPS data to provide information regarding the spatial distribution of gamma-emitting contamination, as shown in Figure 1.

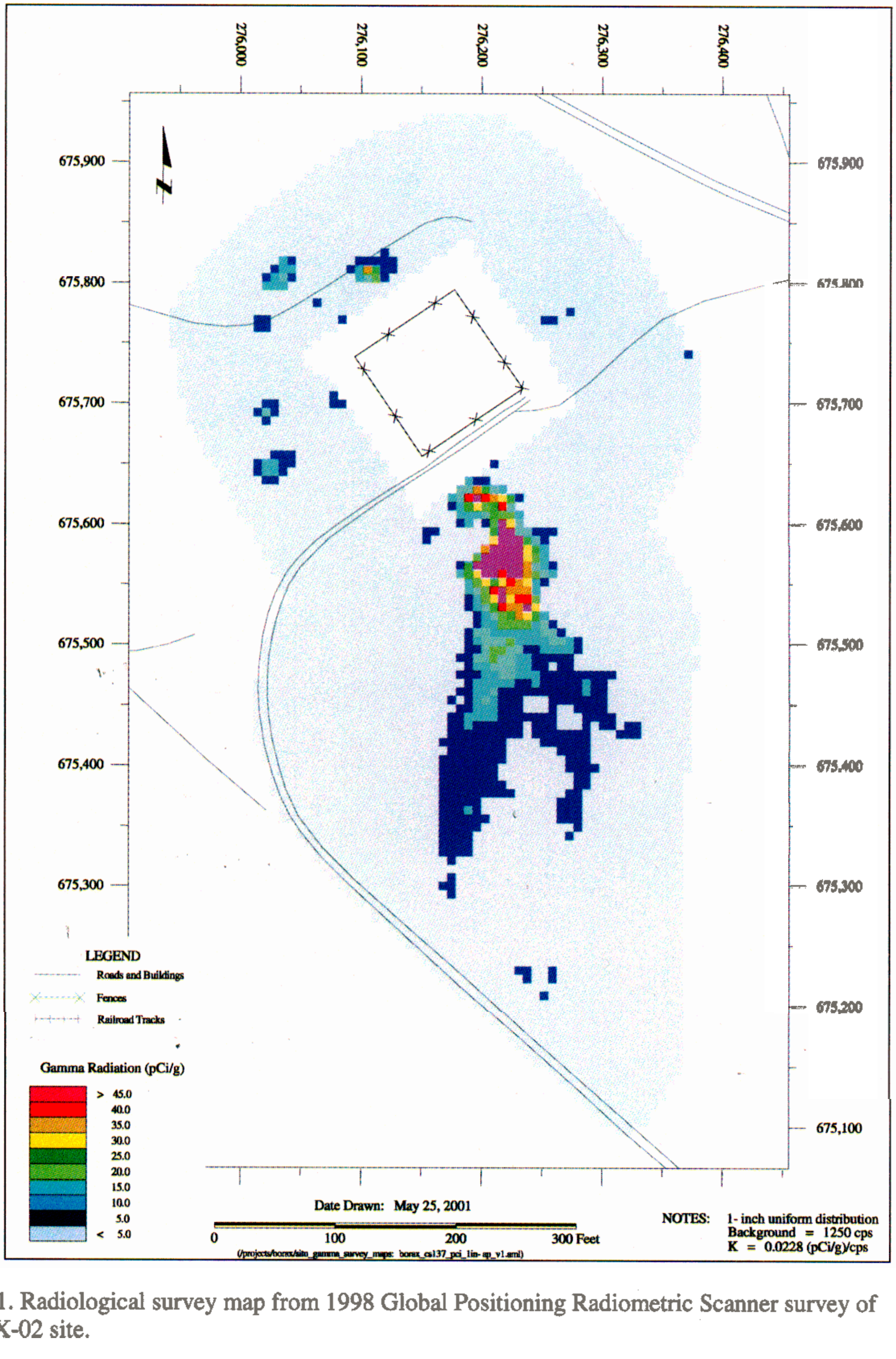

Figure 1. Radiological survey map from 1998 Global Positioning Radiometric Scanner survey of BORAX-02 site.

Before the survey was performed, the GPRS was calibrated, allowing the net count rate data to be converted to ^{137}Cs concentrations in pCi/g (Josten 1997); however, the calibration did not account for the 15 cm (6 in.) of gravel covering the source (contamination) at BORAX I. As a result, the concentrations displayed on the map in Figure 1 are biased low due to the attenuation of the gamma rays through the gravel cover.

3.1.1 Global Positioning Radiometric Scanner Correction Factor Using MicroShield

A correction factor was developed to account for the low bias in the GPRS survey results. The correction factor was estimated through the use of the MicroShield[a] gamma-ray transport code. The correction factor was developed based on the following assumptions/input parameters:

- The dimensions of the estimated rectangular field of view for a 1-second measurement with the GPRS are 9.9 m × 16.5 m (54 × 32 ft) for a total area of 163 m^2 (1,755 ft^2)
- 98% of the contamination is located within 5 cm (2 in.) of the gravel soil interface [i.e., 15 ± 5 cm (6 ± 2 in.) below existing grade].
- The 15-cm (6-in) depth of the gravel layer is uniform over the entire area surveyed.
- Cs-137 is the only significant gamma-ray emitter at the site.
- The density of the soil and gravel at the BORAX-02 site is assumed to be 1.5 g/cm^3.
- The areas shown in Figure 1 that are below 5 pCi/g were considered background and were not corrected.

MicroShield was used to estimate the fluence rates for the photons emitted during the Cs-137 decay. The source geometry used a rectangular volume source (10.2 cm deep × 9.9 m long × 16.5 m wide) representing the field of view of the GPRS for a 1-second count, traveling at a rate of 2.2 m/s (5 mph). An arbitrary concentration of 100 pCi/g was used as the source term input, and models with and without the 15 cm of gravel (shielding) were run in MicroShield. The correction factor was then calculated by taking the ratio of the unshielded (no gravel) fluence rate with buildup to the shielded (15 cm of gravel) fluence rate with buildup. It is important to note here that the source term concentration used in the modeling does not provide a unique correction factor; the same correction factor would have been calculated if the source term was 1 pCi/g or 100 pCi/g, because the photon fluence rates are directly proportional to the source term, and the attenuating materials are constants. The MicroShield model results are provided in Appendix B. From the results, the unshielded fluence rate with buildup is 9.408 $MeV/cm^2/s$, and the shielded fluence rate with buildup is 1.610 $MeV/cm^2/s$, resulting in a correction factor of 5.843. The correction factor was applied to the 1998 GPRS survey data, and the corrected radiological contamination appears as shown in Figure 2.

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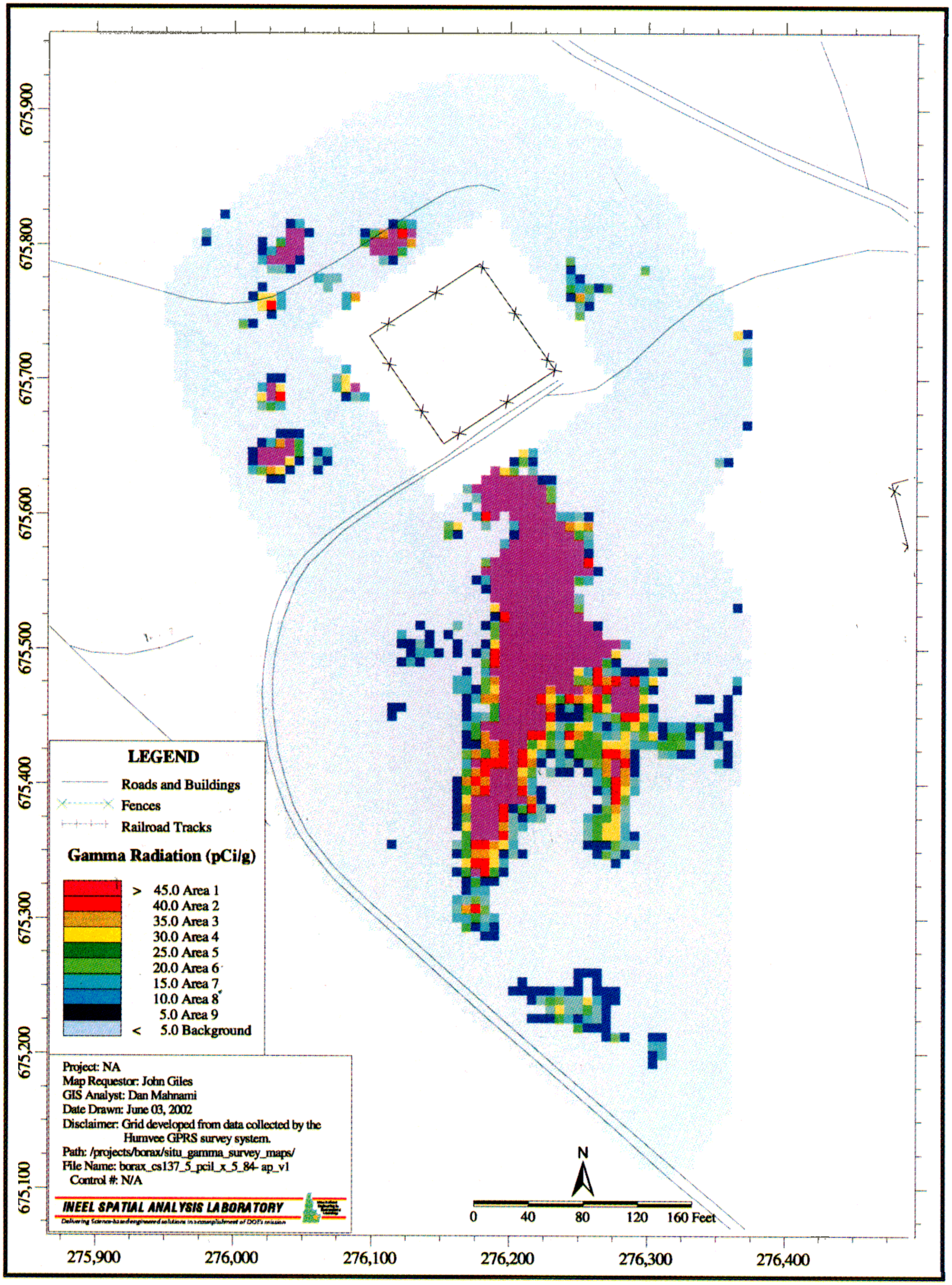

Figure 2. Corrected Global Positioning Radiometric Scanner survey data, 1998 survey of BORAX-02 site.

As shown in Figure 2, the extent of the contamination appears to have increased slightly from that in Figure 1 as a result of the corrected data, which is to be expected due to the shielding effects of the gravel. (Note: The light blue area, i.e., <5 pCi/g, was taken as background; therefore, it was not corrected using the calculated correction factor.)

4. RISK AND DOSE ASSESSMENT

A human-health risk assessment was completed for the BORAX-02 site based on the corrected GPRS data to model soil concentrations for Cs-137 and estimated soil concentrations for Sr-90 and U-235. The methodology used for the risk assessment was from the Track 2 guidance based on EPA guidance for CERCLA (DOE-ID 1994). As discussed previously, a correction factor was established for the GPRS data based on several assumptions. The concentrations of Sr-90 and U-235 for the BORAX-02 site were calculated based on the average ratios of these contaminants to Cs-137. The ratios were also corrected for radioactive decay to May 2002.

4.1 Human Health Risk and Dose Assessment

Carcinogenic risks and the dose to human health were calculated using two different approaches: (1) RESRAD modeling for dose and risk calculations and (2) baseline risk assessment using the INEEL's Track 2 guidance based on EPA guidance for CERCLA (DOE-ID 1994). The baseline risk assessment approach addresses current and future workers and future residents. This section summarizes each approach used, including the input parameters used for the RESRAD modeling, and summary tables of the results for each model. Also included in this section is a discussion of the limitations/uncertainties of the risk assessment.

4.1.1 Nature and Extent

It is difficult to sample the radiologically contaminated soil to get a "representative" concentration due to the heterogeneity of the contaminant distribution as shown by the previous investigations. As such, the risk assessments presented here are based on the extent of contamination as measured by GPRS. As discussed in Section 3.1, the nature and extent of soil contamination at BORAX-02 has been better defined using the corrected GPRS survey data. The results from this type of survey were used to develop representative average concentrations in soil at the site as compared with past grab sampling practices, because the GPRS measurements effectively averages the contamination over the field of view of the detector. For the assessment, the 1.03-acre contaminated area was divided into nine smaller areas with respect to the levels of contamination, and these smaller areas are defined by the modeled Cs-137 soil concentration as shown in Figure 2. The contaminants of concern (COCs) at the BORAX-02 site are Cs-137, Sr-90, and U-235, and the exposure point concentrations (EPCs) in soil used as a basis for the risk assessment are listed in Table 1.

The contaminant concentrations listed for each of the nine individual areas (Figure 2) are averages calculated from the corrected 1998 GPRS survey data. The "Average Concentrations" listed at the bottom of Table 1 are the arithmetic averages for the entire 1.03-acre area at the BORAX-02 site. As stated previously, the Cs-137 concentrations reported in the 1998 GPRS survey were corrected for attenuation and decay. Subsequently, historical data were used to estimate current ratios for Cs-137 to U-235 and Sr-90.

Table 1. Exposure point concentrations for Cesium-137, Strontium -90, and Uranium-235.

Subdivisions of the Soil Contaminated Area	Acres	Cs-137 (pCi/g)	U-235 (pCi/g)	Sr-90 (pCi/g)
Area 1	0.35	116.34	6.73	28.38
Area 2	0.06	38.67	2.24	9.43
Area 3	0.05	34.06	1.97	8.31
Area 4	0.06	29.45	1.70	7.18
Area 5	0.07	25.05	1.45	6.11
Area 6	0.04	20.71	1.20	5.05
Area 7	0.08	15.70	0.91	3.83
Area 8	0.11	11.40	0.66	2.78
Area 9	0.21	6.29	0.36	1.53
Total Acreage	1.03	—	—	—
Average Concentrations	—	51.56	2.98	12.57

The Sr-90 soil concentrations used in this risk assessment were calculated from the ratio of Cs-137 to Sr-90 at the Auxiliary Reactor Area (ARA-23) radiologically contaminated soil site due to the limited quantity of Sr-90 data for the BORAX-02 site. The contaminated soils at the ARA-23 site are a result of the Stationary Low-Power Reactor No. 1 (SL-1) accident and cleanup activities (DOE-ID 1999). Based on similarities between the BORAX-I and SL-1 reactors (i.e., both boiling water reactors and final reactor excursions), the ratio of Cs-137 to Sr-90 are expected to be similar at the BORAX-I site, and since the half-lives of Cs-137 and Sr-90 are both approximately 30 years, the ratio of Cs-137 to Sr-90 has remained unchanged. The concentrations of U-235 for the BORAX-02 site were calculated based on the results of the 1978 Radiological and Environmental Sciences Laboratory (RESL) investigation that showed the mean ratio of Cs-137 to U-235 was 30:1. Prior to calculating the concentrations used in the risk assessment, the Cs-137 concentrations reported by the GPRS were corrected for the shielding effects of the 15-cm gravel layer, and the data were also decay-corrected to May 2002. As a result of the Cs-137 decay since 1978, the current ratio of Cs-137 to U-235 is 17:1. Decay of U-235 was insignificant in calculating the new ratio due to the long half-life of U-235 (i.e., 7.04×10^8 yr). The concentrations for these contaminants, as listed in Table 1, were calculated based on the following ratios:

- Cs-137:U-235 = 17:1
- Cs-137:Sr-90 = 4:1.

Area 1 is the area with the highest average concentration for each of the COCs and is also the largest and most contiguous area represented in this risk assessment.

4.1.2 Assessment Approach

Two different approaches were used to evaluate risk to human receptors. First, the RESRAD code was used to assess external dose based on the subdivided areas (1 through 9) listed in Table 1. This dose was compared to acceptable administrative control levels presented in the *INEEL Radiological Control Manual, Manual 15A* (INEEL 2000a). RESRAD then estimated the excess cancer risk associated with the modeled dose. Second, the baseline risk assessment, following the standard EPA methodology as presented in the OU 10-04 comprehensive remedial investigation/feasibility study (RI/FS) (DOE-ID 2001), was used to estimate risk based on area-weighted averages in soil at all nine of the BORAX-02 site areas. All methods evaluated the exposure to a current and future worker and a future resident. The primary difference in the methodologies is the contaminant distribution assumption. This difference will be discussed in more detail in the following sections.

4.1.3 RESRAD Modeling

RESRAD is a computer code developed for DOE at Argonne National Laboratory-East to calculate site-specific residual radioactive material guidelines as well as radiation dose and excess lifetime cancer risk to a chronically exposed onsite individual (U.S. Department of Energy Argonne National Laboratory).

The RESRAD modeling approach utilizes the site-specific EPCs as calculated in Table 1. RESRAD also uses the actual volume of contaminated soil and allows the user to add a finite layer of clean cover soil above the contaminated soil layer. The assumptions and input parameters used in the RESRAD model more accurately reflect the contaminant distribution at the site of interest. Additionally, RESRAD has been benchmarked against empirical studies and other models to validate and verify the accuracy of the calculations (ANL/EAD 2001). As such, the calculated dose an individual may receive and the subsequent risk associated with that dose from contaminated subsurface soil are more accurate.

4.1.3.1 RESRAD Input. Three hypothetical scenarios were evaluated using RESRAD. These included a current worker now working at the site, a worker beginning work 100 years from now, and a resident living at the site 100 years from now. These scenarios were conservatively chosen because, based on the future land use predictions for BORAX-02, this site will remain under institutional controls beyond the current DOE 100-year institutional control period (2095) (DOE-ID 1997b). The exposure pathways assessed in the current and future worker scenarios include direct exposure, inhalation, and soil ingestion. For the future resident, the exposure pathways assessed include direct exposure, inhalation, and ingestion of plant, meat, milk, soil, and groundwater. The input parameters used for the RESRAD calculations are shown in Table 2.

Table 2. Input parameters for RESRAD for the BORAX-02 site.

Parameter	Current and Future Worker	Future Resident	Units
Area of contaminated zone	Area specific	Area specific	m^2
Thickness of contaminated zone	0.1016	0.1016	meters
Length parallel to aquifer flow	Area specific	Area specific	meters
Cover depth	0.15	0.15	meters
Density of cover material	1.5	1.5	grams/cm^3
Cover erosion rate	0.001	0.001	meters/yr
Density of contaminated zone	1.5	1.5	grams/cm^3
Contaminated zone erosion rate	0.001	0.001	meters/yr
Contaminated zone total porosity	0.4	0.4	
Contaminated zone field capacity	0.2	0.2	
Contaminated zone hydraulic conductivity	10	10	meters/yr
Humidity in air	8	8	grams/m^3
Evapotranspiration coefficient	0.5	0.5	
Wind speed	2	2	meters/s
Precipitation	0.1	0.1	meters/yr
Irrigation	0.2	0.2	meters/yr

Table 2. (continued)

Parameter	Current and Future Worker	Future Resident	Units
Run-off coefficient	0.2	0.2	
Density of saturated zone	—	1.5	grams/cm^3
Saturated zone total porosity	—	0.4	
Saturated zone effective porosity	—	0.2	
Saturated zone field capacity	—	0.2	
Saturated zone hydraulic conductivity	—	100	meters/yr
Saturated zone hydraulic gradient	—	0.02	
Thickness of unsaturated zone	—	4	meters
Density of unsaturated zone	—	1.5	grams/cm^3
Unsaturated zone total porosity	—	0.4	
Unsaturated zone effective porosity	—	0.2	
Unsaturated zone field capacity	—	0.2	
Unsaturated zone hydraulic conductivity	—	10	meters/yr
Inhalation rate	8,400	8,400	m^3/yr
Mass loading for inhalation	0.0001	0.0001	grams/m^3
Exposure duration	25	30	years
Indoor dust filtration factor	0.4	0.4	
External gamma shielding factor	0.7	0.7	
Indoor time fraction	0.5	0.5	
Outdoor time fraction	0.25	0.25	
Soil ingestion	36.5	36.5	grams/yr
Fruit, vegetable, and grain consumption	—	160	kilograms/yr
Leafy vegetable consumption	—	14	kilograms/yr
Milk consumption	—	92	liters/yr
Meat and poultry consumption	—	63	kilograms/yr
Drinking water intake	—	510	liters/yr
Livestock fodder intake for meat	—	68	kilograms/day
Livestock fodder intake for milk	—	55	kilograms/day
Livestock water intake for meat	—	50	liters/day
Livestock water intake for milk	—	160	liters/day
Livestock intake of soil	—	0.5	kilograms/day
Mass loading for foliar deposition	—	0.0001	grams/m^3
Depth of soil mixing layer	—	0.15	meters
Depth of roots	—	0.9	meters

4.1.3.2 RESRAD Results. The results of the risk calculations for each of the nine soil contaminated areas at BORAX-02 for the current worker, future worker, and the future resident scenarios are present in Tables 3 through 5. Excess cancer risks were summed across all pathways and all contaminants of potential concern for each area. The primary exposure pathway for all three scenarios was direct exposure from Cs-137. Figure 3 is a graph showing excess cancer risk summed across all nuclides and exposure pathways for both the current and future worker based on the average concentrations of all COCs in the contaminated area. Figure 4 is a graph showing excess cancer risk for the future resident based on the average concentration of all COCs in the contaminated area. Excess cancer risk is also summed a crossed all nuclides and exposure pathways in Figure 4.

Table 3. Carcinogenic risks to the current worker.

Area	Acres	Risk	Dose (mrem/yr)
1	0.35	3.30E-04	1.98E+01
2	0.06	1.10E-04	6.57E+00
3	0.05	9.65E-05	5.79E+00
4	0.06	8.35E-05	5.01E+00
5	0.07	7.10E-05	4.26E+00
6	0.04	5.87E-05	3.52E+00
7	0.08	4.45E-05	2.67E+00
8	0.11	3.23E-05	1.94E+00
9	0.21	1.78E-05	1.07E+00
Average	1.03	1.46E-04	8.76E+00

Table 4. Carcinogenic risks to the future worker (in 100 years).

Area	Acres	Risk	Dose (mrem/yr)
1	0.35	1.27E-04	7.63E+00
2	0.06	4.17E-05	2.53E+00
3	0.05	3.66E-05	2.23E+00
4	0.06	3.17E-05	1.93E+00
5	0.07	2.70E-05	1.64E+00
6	0.04	2.20E-05	1.35E+00
7	0.08	1.70E-05	1.03E+00
8	0.11	1.24E-05	7.46E-01
9	0.21	6.86E-06	4.12E-01
Average	1.03	5.64E-05	3.38E+00

Table 5. Carcinogenic risks to the future resident (in 100 years).

Area	Acres	Risk	Dose (mrem/yr)
1	0.35	1.54E-04	7.96E+00
2	0.06	4.91E-05	2.56E+00
3	0.05	4.31E-05	2.25E+00
4	0.06	3.74E-05	1.95E+00
5	0.07	3.19E-05	1.66E+00
6	0.04	2.59E-05	1.36E+00
7	0.08	2.01E-05	1.04E+00
8	0.11	1.47E-05	7.60E-01
9	0.21	8.26E-06	4.27E-01
Average	1.03	6.92E-05	3.58E+00

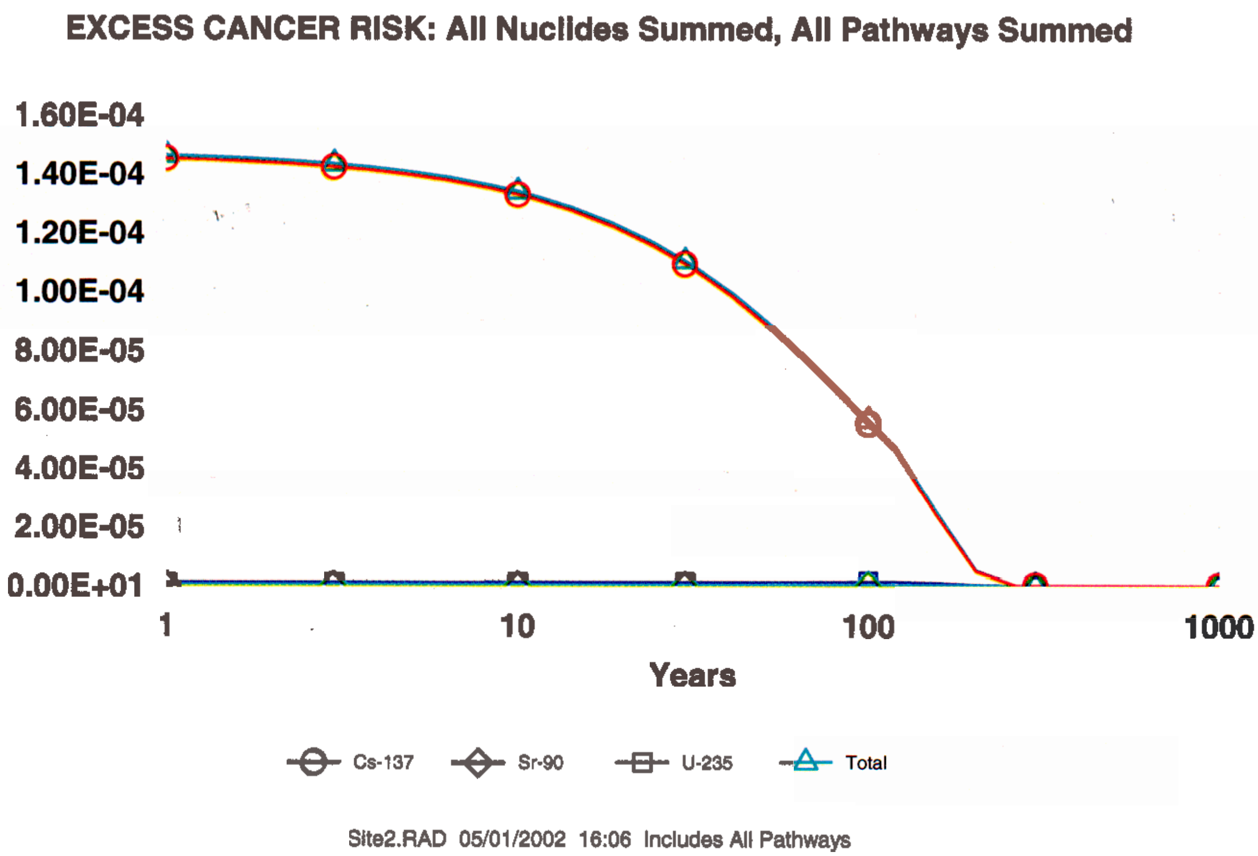

Figure 3. Excess cancer risk for the current and future worker based on the average concentration of all contaminants of concern in the contaminated area.

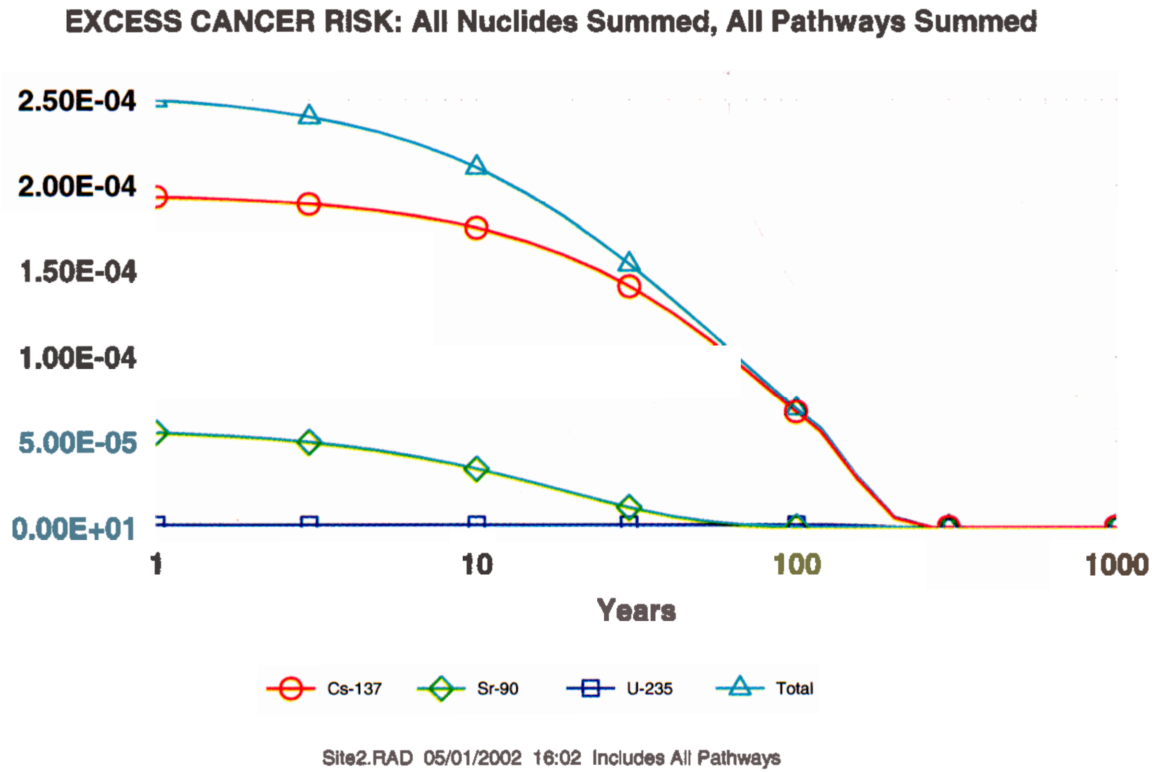

Figure 4. Excess cancer risk for the future resident based on the average concentration of all contaminants of concern in the contaminated area.

The results from the RESRAD modeling assessment showed that Cs-137 was the primary COC and contributed most of the risk in all areas. Modeled soil concentrations of Cs-137 at Areas 1 and 2 exceeded acceptable risk levels to the current worker, and Area 1 exceeded acceptable risk levels (1E-04) to the future worker or future resident. Additionally, when the entire area of contamination was considered as a whole, the soil concentrations of Cs-137 exceeded acceptable risk levels (1E-04) based on a current worker scenario. For Area 1 the risk to a future worker and resident would drop below acceptable levels in 130 years due to the decay of Cs-137.

The total excess risk averaged over the nine areas was above acceptable levels (1E-04) for the current worker; however, excess risks for the future worker and future resident were below 1E-04. Institutional controls currently in place at this site, in accordance with the draft OU 10-04 record of decision (ROD) (DOE-ID 2002), would mitigate any hazards to a worker or future resident beyond the current institutional control period of 2095. Additionally, contaminant concentrations are likely to decay below regulatory levels before institutional controls are removed. If the site were to be considered for release prior to the end of the institutional control period in 2095, then a detailed evaluation of the risk from contamination remaining in the area would need to be made. The release would require concurrence from DOE-ID, EPA, and the State of Idaho.

The dose to the current worker within Area 1 is 19.8 mrem/yr. The *INEEL Radiological Control Manual* (INEEL 2000a) imposes an administrative control level of 2.0 rem/yr (this correlates to an EPA level of excess risk of approximately 6E-03). The RESRAD calculated excess cancer risk to the current worker at Area 1 is 3E-04. Additionally, the maximum measured dose rate of 45 μR/hr from the 1978 radiological survey (see Appendix A) is less than the 60 μR/hr limit for a soil contamination area as detailed in MCP-187, "Posting Radiological Control Areas" (INEEL 2000b). Although the risk is not within limits acceptable under CERCLA, the dose is within administrative control limits based on the calculated RESRAD dose. For this reason, there is no requirement for any action to control access to the BORAX-02 site using the agreed upon administrative levels.

4.1.4 Baseline Risk Assessment

The BORAX-02 site was also assessed using standard baseline risk assessment methodology for comparison purposes. The methodology used for the risk assessment was from the Track 2 guidance based on EPA guidance for CERCLA (DOE-ID 1994). The same three exposure scenarios (i.e., current and future worker, and future resident) were used to calculate new cancer risks. Although this methodology does not account for the soil cover over the contamination layer, it is less conservative (particularly for the external exposure pathway) in that is assumes the contamination is homogeneously distributed from the surface down to a pre-defined depth (i.e., 10 ft). The volume of each soil bin was calculated according to the exposure scenario being evaluated. The soil bin depths used in this risk assessment include 0 to 0.15 m (0 to 0.5 ft) and 0 to 1.2 m (0 to 4 ft) for the surface soil and subsurface soil, respectively, in the occupational worker scenarios, and 0 to 3 m (0 to 10 ft) for the subsurface soil in the residential scenario. In determining the concentration of radionuclides in each soil bin depth for the baseline risk assessment, the first step was to calculate the total activity in the entire volume for each of the nine areas from the original EPCs listed in Table 1. This was done using the following equation:

$$\text{Activity} = \text{EPC} \times \text{D} \times \text{A} \quad (1)$$

EPC = contaminant and area-specific exposure point concentration (pCi/g)

D = soil density (1,500,000 g/m^3)

A = volume of the soil in contaminated zone (m^3).

Once the activity for each radionuclide was determined, the individual activities were spread throughout the soil bin being assessed for each scenario, and a new exposure point concentration (NEPC) was calculated. The NEPCs were calculated for each radionuclide using the following equation:

$$\text{NEPC} = \text{Activity}/(\text{D} \times \text{B}) \quad (2)$$

NEPC = newly calculated EPC (pCi/g)

D = soil density (1,500,000 g/m^3)

B = volume of the bin (m^3)

Although the NEPCs are based on larger volumes of soil, the original amount of activity remains the same. The NEPCs at the various bin depths can be found in Table 6.

Table 6. New exposure point concentrations at the various bin depths.

	0–0.5 ft			0–4 ft			0–10 ft		
	Cs-137	Sr-90	U-235	Cs-137	Sr-90	U-235	Cs-137	Sr-90	U-235
Area 1	7.76E+01	1.89E+01	4.49E+00	9.70E+00	2.37E+00	5.61E-01	3.88E+00	9.46E-01	2.24E-01
Area 2	2.58E+01	6.29E+00	1.49E+00	3.22E+00	7.86E-01	1.87E-01	1.29E+00	3.14E-01	7.47E-02
Area 3	2.27E+01	5.54E+00	1.31E+00	2.84E+00	6.93E-01	1.64E-01	1.14E+00	2.77E-01	6.57E-02
Area 4	1.96E+01	4.79E+00	1.13E+00	2.45E+00	5.98E-01	1.42E-01	9.82E-01	2.39E-01	5.67E-02
Area 5	1.67E+01	4.07E+00	9.67E-01	2.09E+00	5.09E-01	1.21E-01	8.35E-01	2.04E-01	4.83E-02
Area 6	1.38E+01	3.37E+00	8.00E-01	1.73E+00	4.21E-01	1.00E-01	6.90E-01	1.68E-01	4.00E-02
Area 7	1.05E+01	2.55E+00	6.07E-01	1.31E+00	3.19E-01	7.58E-02	5.23E-01	1.28E-01	3.03E-02
Area 8	7.60E+00	1.85E+00	4.40E-01	9.50E-01	2.32E-01	5.50E-02	3.80E-01	9.27E-02	2.20E-02
Area 9	4.19E+00	1.02E+00	2.40E-01	5.24E-01	1.28E-01	3.00E-02	2.10E-01	5.10E-02	1.20E-02
Average Over Entire Area	3.44E+01	8.38E+00	1.99E+00	4.30E+00	1.05E+00	2.48E-01	1.72E+00	4.19E-01	9.93E-02

The NEPCs were then used to calculate the excess cancer risks through each of the exposure pathways. The current and future worker exposure pathways included ingestion of soil, inhalation of fugitive dust, and external radiation exposure. Exposure pathways for the future resident included ingestion of soil, ingestion of groundwater, ingestion of homegrown produce, inhalation of fugitive dust, and external radiation exposure. The results of these calculations are presented in Tables 7 through 9.

Table 7. Excess cancer risk to a current worker.

	Ingestion of Soil	Inhalation of Fugitive Dust	External Radiation Exposure	Total by Area
Area 1	1.07E-06	2.35E-08	3.93E-05	4.04E-05
Area 2	3.56E-07	2.35E-08	3.93E-05	3.97E-05
Area 3	3.14E-07	2.35E-08	3.93E-05	3.96E-05
Area 4	2.71E-07	2.35E-08	3.93E-05	3.96E-05
Area 5	2.31E-07	2.35E-08	3.93E-05	3.95E-05
Area 6	1.91E-07	2.35E-08	3.93E-05	3.95E-05
Area 7	1.45E-07	2.35E-08	3.93E-05	3.94E-05
Area 8	1.05E-07	2.35E-08	3.93E-05	3.94E-05
Area 9	5.78E-08	2.35E-08	3.93E-05	3.94E-05
Average for Entire Area	4.75E-07	2.36E-08	3.94E-05	3.98E-05

Table 8. Excess cancer risk to a future worker (in 100 years).

	Ingestion of Soil	Inhalation of Fugitive Dust	External Radiation Exposure	Total by Area
Area 1	1.61E-07	1.40E-08	4.29E-06	4.46E-06
Area 2	5.35E-08	1.40E-08	4.29E-06	4.36E-06
Area 3	4.71E-08	1.40E-08	4.29E-06	4.35E-06
Area 4	4.07E-08	1.40E-08	4.29E-06	4.34E-06
Area 5	3.47E-08	1.40E-08	4.29E-06	4.34E-06
Area 6	2.87E-08	1.40E-08	4.29E-06	4.33E-06
Area 7	2.17E-08	1.40E-08	4.29E-06	4.33E-06
Area 8	1.58E-08	1.40E-08	4.29E-06	4.32E-06
Area 9	8.66E-09	1.40E-08	4.29E-06	4.31E-06
Average for Entire Area	7.13E-08	1.40E-08	4.30E-06	4.37E-06

Table 9. Excess cancer risk to a future resident (in 100 years).

	Ingestion of Soil	Ingestion of Groundwater	Ingestion of Homegrown Produce	Inhalation of Fugitive Dust	External Radiation Exposure	Total by Area
Area 1	3.15E-08	5.92E-22	2.78E-23	3.52E-09	8.25E-06	8.29E-06
Area 2	1.05E-08	5.92E-22	2.75E-23	3.52E-09	8.25E-06	8.27E-06
Area 3	9.21E-09	5.92E-22	2.75E-23	3.52E-09	8.25E-06	8.26E-06
Area 4	7.96E-09	5.92E-22	2.75E-23	3.52E-09	8.25E-06	8.26E-06
Area 5	6.78E-09	5.92E-22	2.74E-23	3.52E-09	8.25E-06	8.26E-06
Area 6	5.60E-09	5.92E-22	2.74E-23	3.52E-09	8.25E-06	8.26E-06
Area 7	4.25E-09	5.92E-22	2.74E-23	3.52E-09	8.25E-06	8.26E-06
Area 8	3.08E-09	5.92E-22	2.74E-23	3.52E-09	8.25E-06	8.26E-06
Area 9	1.69E-09	5.92E-22	2.74E-23	3.52E-09	8.25E-06	8.26E-06
Average for Entire Area	1.39E-08	5.92E-22	2.75E-23	3.53E-09	8.28E-06	8.27E-06

The results of the baseline risk assessment show that no areas at the BORAX-02 site have excess cancer risk above 1E-04. The primary exposure pathway was external radiation and the primary radionuclide was Cs-137.

4.1.5 Uncertainties of the Risk Assessment

To ensure that the risk estimates are conservative, health protective assumptions that tend to bound the plausible upper limits of human health risks are used throughout the risk assessment. Therefore, risk estimates that may be calculated by other risk assessment methods are not likely to be significantly higher than the estimates presented in this document.

Uncertainty in this risk assessment is produced by uncertainty factors in the following four stages of analysis:

1. Data collection and evaluation

2. Exposure assessment

3. Toxicity assessment

4. Risk characterization.

4.1.5.1 Data Collection and Evaluation Uncertainties. Uncertainties associated with data collection and evaluation are produced by variability in observed concentrations from sampling design and implementation, laboratory analysis methods, seasonality, contaminant levels, and natural concentration. Although the measurement uncertainty associated with the GPRS data is larger than what would be obtained from a laboratory sample, the GPRS provides a much more representative "picture" of the contamination than discrete sampling due to the heterogeneity of the contaminant distribution. Additional uncertainty is associated with the correction of the GPRS data for the shielding effects of the gravel layer, primarily due to the non-uniformity of the layer and with estimating the Sr-90 and U-235 concentrations from ratios; however, as was shown in the risk assessment calculations, Sr-90 and U-235 were not the primary risk drivers.

All of the areas evaluated in the risk assessment have varying levels of uncertainty associated with the contaminant concentrations. In addition, all of the evaluated concentrations were estimated using conservative assumptions about the nature and extent of contamination at the various areas. The concentration term uncertainties and conservative assumptions are summarized in Table 10.

4.1.5.2 Exposure Assessment. Uncertainties associated with the exposure assessment are produced by characterizing transport, dispersion, and transformation of contaminants of potential concern in the environment; establishing exposure settings; and deriving estimates of chronic intake. The initial characterization that defines the exposure setting for a site involves many professional judgments and assumptions. Definition of the physical setting, population characteristics, and selection of the chemicals included in the risk assessment are examples of areas for which a quantitative estimate of uncertainty cannot be achieved because of the inherent reliance on professional judgment.

The only contaminant loss mechanism considered in the baseline risk assessment is radioactive decay. Other loss mechanisms such as leaching and wind erosion are assumed to be negligible. The reason for this assumption is that environmental sampling has shown that most contaminants do not migrate from most INEEL sites. As a result of this observation, very few studies have been performed to evaluate these mechanisms. Therefore, very little site-specific information is available to estimate the exact effects of these removal mechanisms.

Omitting removal mechanisms other than radioactive decay tends to overestimate risk for all exposure routes, because it leads to assuming a given mass of contaminant will cause exposures by multiple exposure routes. For example, leaching is omitted in the soil pathway analysis even though leaching is the mechanism that produces the contamination evaluated in the groundwater pathway analysis. As a result of the omission, a given mass of contamination can affect both the soil pathway and groundwater pathway risk analysis results. Upper-bound infiltration and contaminant leachability assumptions are used in the groundwater pathway analysis to estimate future groundwater contaminant concentrations. Applying these same upper-bound assumptions to the soil pathway analysis would likely produce an underestimation of soil pathway risks. To avoid this possibility, leaching is omitted from the soil pathway analysis, so that upper-bound risk results are calculated for both the soil pathway and groundwater pathway exposure routes.

4.1.5.3 Toxicity Assessment. Several important measures of toxicity are needed to conduct an assessment of risk to human health. Slope factors are applied to the oral and inhalation exposures to carcinogens. Uncertainty associated with slope factors is accounted for by an assigned weight-of-evidence rating that reflects the likelihood of the toxicant being a human carcinogen.

4.1.5.4 Risk Characterization. The last step in the risk assessment is risk characterization. Risk characterization is the process of integrating the results of the exposure assessment and the toxicity assessment. The uncertainties defined throughout the analysis process are combined and presented as part of the risk characterization to provide an understanding of the overall uncertainty in the estimate of risk. This qualitative assessment of uncertainty is presented in Table 10.

5. CONCLUSION

A site assessment was performed for the BORAX-I site to evaluate the dose and risk associated with the residual contamination remaining in the surface and subsurface soils outside of the engineered cover. Upon review of the historical data sets, and based upon the heterogeneous nature of the contaminant distribution, the 1998 GPRS survey data were selected for use in the assessment. Prior to performing the assessment, the Cs-137 data were corrected for the shielding provided by the 15-cm (6-in.) gravel layer and for radioactive decay to May 2002. Additionally, historical data from the SL-1 site and the BORAX-I site were used to establish ratios of Sr-90 and U-235, respectively, to Cs-137 in order to estimate the concentrations of Sr-90 and U-235 in the soils at the BORAX-I site.

The assessment was performed using two methods; namely, RESRAD modeling, and the standard baseline methodology from the Track 2 guidance based on EPA guidance for CERCLA (DOE-ID 1994). Calculations for both methods were based on corrected GPRS data for Cs-137 and estimated concentrations for Sr-90 and U-235.

The results from the RESRAD modeling assessment showed that Cs-137 was the primary COC for external exposure. Modeled soil concentrations of Cs-137 at Areas 1, 2 and the entire area average exceeded acceptable risk levels (1E-04) to the current worker. Area 1 also exceeded acceptable risk levels (1E-04) to the future worker and future resident. At Area 1, the risk level to a future worker and future resident would drop below acceptable levels in 130 years due to decay. Other than Areas 1 and 2 and the total area averaged, no other single area exceeded an acceptable risk level (1E-04) to potential receptors.

Using the baseline risk assessment methodology, none of the nine individual areas, nor the entire area of contamination, presented unacceptable risks to the current and future worker or to the future resident. However, this approach is less conservative than the RESRAD modeling.

The primary pathway for concern from both risk assessment approaches is through direct exposure to external radiation, and the primary radionuclide of concern is Cs-137. The direct exposure strategy used in the RESRAD model is more appropriate for assessing risk through this pathway. Specifically to the BORAX-02 site, the volume of contaminated soil used in the modeling calculations is a direct measure of the volume of contaminated soil assumed to be at BORAX-02 (unlike the baseline risk assessment, which uses an adjusted average in a larger soil volume, as described in Section 4.1.4). The RESRAD modeling also included the 15-cm (6-in) thick layer of gravel material covering the contaminated soil. Therefore, RESRAD will more realistically model the external dose to a current and future worker and a future resident and is the better method for determining the external dose. Although RESRAD is more conservative, this model more realistically depicts the risk to the current and future worker and to the future resident.

Table 10. Baseline human health assessment uncertainty factors.

Uncertainty Factor	Effect of Uncertainty	Comment
Source term assumptions	May overestimate or underestimate risk	All contaminants are assumed to be completely available for transportation away from the source zone. In reality, some contaminants may be chemically or physically bound to the source zone and unavailable for transport.
Natural infiltration rate	May overestimate risk	A conservative value of 0.1 cm/yr was used for this parameter.
Moisture content	May overestimate or underestimate risk	Soil moisture contents vary seasonally in the upper vadose zone and may be subject to measurement error.
Water table fluctuations	May slightly overestimate or underestimate risk	The average value used is expected to be representative of the depth over the 30-year exposure period.
Mass of contaminants in soils estimated by assuming a uniform contamination concentration in the source zone	May overestimate or underestimate risk	There is a possibility that most of the activity of a given contaminant at a given site may exist in a hot spot. If this condition exists, the activity of the contaminant used in the analysis might be underestimated. However, in situ measurements tend to provide an average concentration over a large area, and the effect of the uncertainty in overestimating or underestimating the risk is dependant upon the true activity of the radionuclide contaminants at the site.
Plug flow assumption in groundwater transport	Could overestimate or underestimate risk	Plug flow models are conservative relative to concentrations, because dispersion is neglected, and mass fluxes from the source to the aquifer differ only by the time delay in the unsaturated zone (the magnitude of the flux remains unchanged). For radionuclides, the plug flow assumption may or may not be conservative. Based on actual travel time, the radionuclide groundwater concentrations could be overestimated or underestimated, because a longer travel time allows for more decay. If the concentration decrease from the travel time delay is larger than the neglected dilution from dispersion, the model will not be conservative.
No migration of contaminants from the soil source prior to sampling	Could overestimate or underestimate risk	The result of not modeling contaminant migration from the soil before sampling is dependent on the contaminant's half-life and mobility characteristics.
Chemical form assumptions	Could overestimate or underestimate risk	In general, the methods and inputs used in contaminant migration calculations, including assumptions about chemical forms of contaminants, were chosen to err on the protective side. All contaminant concentrations and mass are assumed available for transport. This assumption results in a probable overestimate of risk.
Exposure scenario assumptions	May overestimate risk	The likelihood of future scenarios has been qualitatively evaluated as follows: Resident—improbable Industrial—credible. The likelihood of future on-site residential development is small. If future residential use of this site does not occur, then the risk estimates calculated for future on-site residents are likely to overestimate the true risk associated with future use of this site.

Table 10. (continued).

Uncertainty Factor	Effect of Uncertainty	Comment
Exposure parameter assumptions	May overestimate risk	Assumptions about media intake, population characteristics, and exposure patterns may not characterize actual exposures.
Receptor locations	May overestimate risk	Groundwater ingestion risks are calculated for a point at the downgradient edge of an equivalent rectangular area. The groundwater risk at this point is assumed to be the risk from groundwater ingestion at every point within BORAX-02 boundaries. Changing the receptor location will only affect the risks calculated for the groundwater pathway, because all other risks are site-specific or assumed constant at every point within the BORAX-02 boundaries.
For the groundwater pathway analysis, all contaminants were assumed to be homogeneously distributed in a large mass of soil for the baseline risk assessment.	May overestimate or underestimate risk	The total mass of each COC is assumed to be homogeneously distributed in the soil volume beneath each BORAX-02 area. This assumption tends to maximize the estimated groundwater concentrations produced by the contaminant inventories, because homogeneously distributed contaminants would not have to travel far to reach a groundwater well drilled anywhere within the BORAX-02 boundary. However, groundwater concentrations may be underestimated for a large mass of contamination (located in a small area with a groundwater well drilled directly downgradient).
The entire inventory of each contaminant is assumed to be available for transport along each pathway	May overestimate risk	Only a portion of each contaminant's inventory will be transported by each pathway.
Exposure duration	May overestimate risk	The assumption that an individual will work or reside at a site for 25 or 30 years is conservative. Short-term exposures involve comparison to subchronic toxicity values, which are generally less restrictive than chronic values.
Noncontaminant-specific constants (not dependent on contaminant properties)	May overestimate risk	Conservative or upper-bound values were used for all parameters incorporated into intake calculations.
Exclusion of some hypothetical pathways from the exposure scenarios	May underestimate risk	Exposure pathways are considered for each scenario and eliminated only if the pathway is either incomplete or negligible compared to other evaluated pathways.
Model does not consider biotic decay	May overestimate risk	Biotic decay would tend to reduce contamination over time.
Occupational intake value for inhalation is conservative	Slightly overestimates risk	Standard exposure factors for inhalation have the same value for occupational as for residential scenarios, though occupational workers would not be onsite all day.
Use of cancer slope factors	May overestimate risk	Slope factors are associated with upper 95th percentile confidence limits. They are considered unlikely to underestimate true risk.

RESRAD risk assessment results indicated that modeled soil concentrations of Cs-137 at Area 1, Area 2, and the total 1.03-acre area averaged exceeded acceptable risk levels (1E-04) to the current worker, and Area 1 exceeded acceptable risk levels for the future worker and future resident. However, the calculated dose to the current worker within all areas was less than the administrative controls presented in the *INEEL Radiological Control Manual* (INEEL 2000a). Area 1 (0.35 acre) was calculated to have a potential dose of 19.8 mrem/yr, and Area 2 (0.06 acre) was calculated to have a potential dose of 6.57 mrem/yr to the current worker. The average dose over the total 1.03-acre area of contamination was calculated to be 8.8 mrem/yr to the current worker. Similarly, the potential dose at Area 1 is 7.5 mrem/yr to the future worker and 7.96 mrem/yr for the future resident. These annual doses are significantly less than the *INEEL Radiological Control Manual* (INEEL 2000a) administrative control level of 2.0 rem/yr. A dose level of 2.0 rem/yr correlates to a level of excess risk of approximately 6E-03. Excess cancer risk within Area 1 to the current worker is 3E-04 and 1.3E-04 for the future worker.

From the results of this assessment it is concluded that the dose to both current and future receptors is acceptable at this site, although two areas of contamination may exceed risk-based levels (1E-04). However, this risk may be acceptable based on the uncertainties associated with the analysis, combined with the understanding that the residual Cs-137 activity at the site will decay to acceptable risk levels in approximately 130 years. Until that time, it appears that the proposed institutional controls and land use restrictions listed in the draft ROD for OUs 6-05 and 10-04 (DOE-ID 2002) will remain in place at the site and will be adequately protective of human receptors under the scenarios assessed.

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Appendix A

Previous Site Investigations

Appendix A
Previous Site Investigations

Radiological Surveys and Soil Sampling: 1978

The Department of Energy Radiological and Environmental Sciences Laboratory (RESL) performed a multi-phase study in 1978 to assess the distribution of radioactivity at the Boiling Water Reactor Experiment I (BORAX-I) burial ground. Radiation surveys were performed in the spring and fall of 1978. Exposure rates at 1 m (3 ft) above ground were measured using a high-pressure ionization chamber, and the results are presented in Figure A-1. The highest exposure rate recorded was 45 μR/hr over the central portion of the gravel covering southeast of the former reactor location. Elevated exposure rates were also found along the northwest and southwest perimeter of the gravel covering.

A portable gamma-ray spectroscopy system was also used to identify gamma-emitting radionuclides, and soil profile samples were collected from five locations within the gravel-covered area in order to assess the deposition and migration of activity (if any). Gamma-ray spectroscopy results from the in situ measurements and laboratory analyses of the soil samples showed that Cs-137 and U-235 were the only detectable gamma-emitting radionuclides still present at the site. Profile sampling showed that 98% of the subsurface contamination was located within 5 cm (2 in.) of the gravel/soil interface. The remainder (i.e., 2%) suggested that gaps existed in the gravel covering and that limited portions of the covering were disturbed at some point after the gravel was applied. Cesium-137 and U-235 were detected in all of the 1978 profile samples, and the mean ratio of Cs-137 to U-235 activity was 30:1 (INEL 1995).

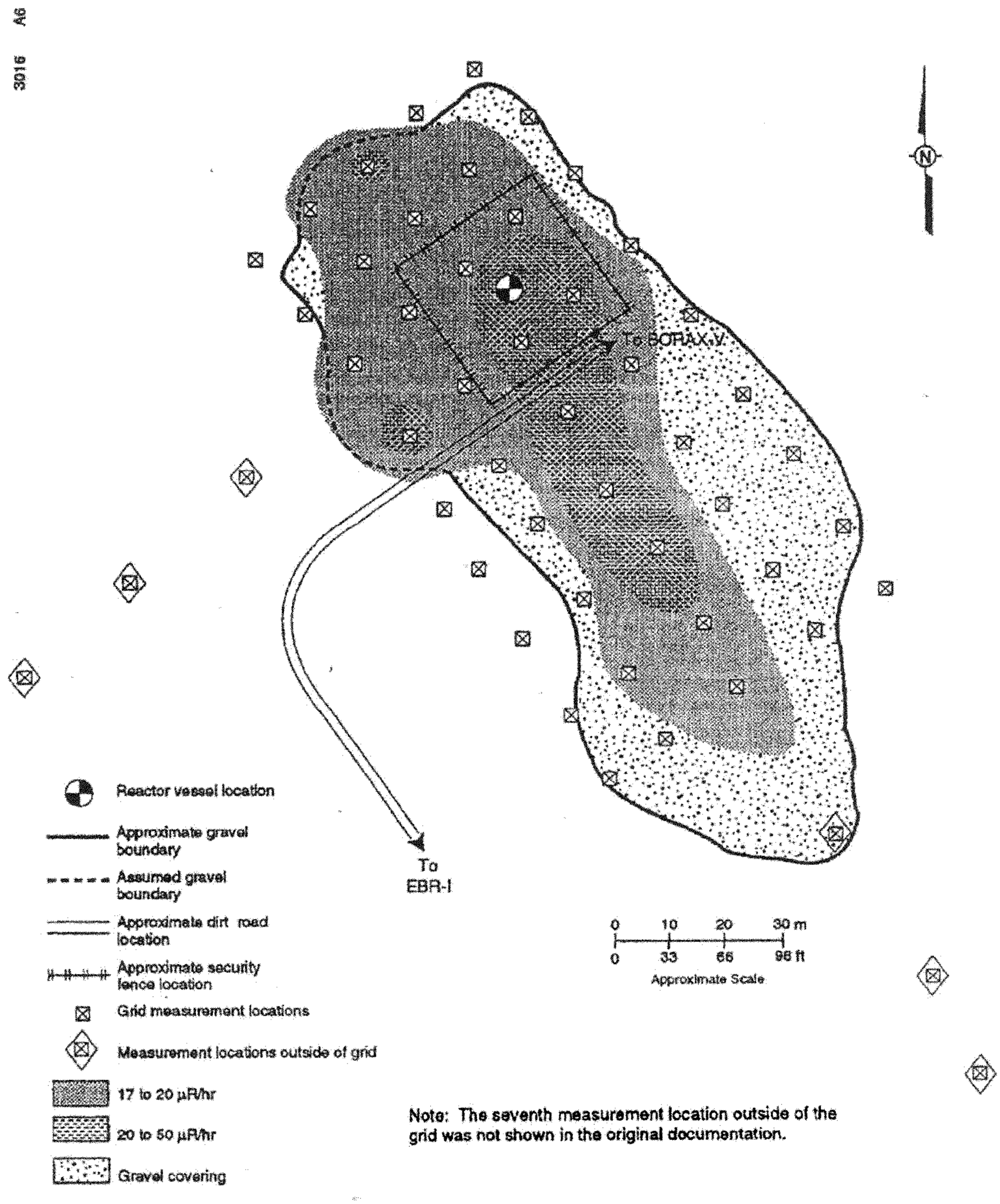

Figure A-1. Results of 1978 radiation survey.

Radiological Surveys and Soil Sampling: 1980

Surface and subsurface radiological surveys and soil sampling tasks were performed in June and November 1980. As directed by decontamination and dismantlement personnel, the area was staked out on a 7.6-m (25-ft) grid that extended 152 m (500 ft) north and 91 m (300 ft) east from a reference point southwest of the reactor burial site. Direct measurements and sampling efforts were conducted at the grid nodes. The June 1980 survey was comprised of in situ gamma spectrometric measurements of surface soils, collection and analysis of surface and subsurface soil samples, and borehole gamma-ray spectroscopy measurements using a sodium-iodide based system. The survey conducted in November 1980 consisted of a surface radiation survey using a shielded pancake probe and a digital rate meter.

The results from the June 1980 in situ measurements of surface soils showed that Cs-137 was the only manmade, gamma-emitting radionuclide detected at four of the five measurement locations, with the highest count rates located nearest the reactor burial ground. Cobalt-60 was identified at one of the locations that was attributed to the long (i.e., 4,000-second) count time. This survey did not quantify the Cs-137 activity due to the heterogeneous distribution of the contamination. Surface soil samples and subsurface samples down to a dept of 61 cm (24 in.) were collected and analyzed at the INEEL Radiation Measurements Laboratory (RML), and the results are shown in Table A-1 (Randolph, Coates, and Rowsell 1980; Smith 1980).

Table A-1. Soil sample analytical results from June 1980 BORAX survey.

Location	Depth (in.)	Cs-137 Concentration (pCi/g)
N275 E100	Surface	4.2 ± 0.4
	6	Non-detect (ND)
	12	ND
	18	ND
	24	ND
N150 E50	Surface	2.8 ± 0.3
	6	0.7 ± 0.2
	12	ND
	18	0.19 ± 0.06
	24	ND
N200 E250	Surface	4.1 ± 0.4
	6	ND
	12	0.6 ± 0.2
	18	ND
	24	ND
N325 E250	Surface	7.0 ± 0.4
	6	ND
	12	0.6 ± 0.1
	18	ND
	24	ND
N100 E175	Surface	2.3 ± 0.3
	6	ND
	12	ND
	18	ND
	24	ND

Table A-1. (continued)

Location	Depth (in.)	Cs-137 Concentration (pCi/g)
N350 E50	Surface	1.4 ± 0.2
	6	ND
	12	ND
	18	ND
	24	ND

As can be seen from Table A-1, the Cs-137 concentrations in the soils ranged from less than the method detection limit to a maximum of 7.0 ± 0.4 pCi/g. In addition, in contrast with the 1978 study conducted by RESL, the maximum concentrations at all sample locations in the June 1980 survey occurred at the surface.

Thirty-seven boreholes were dug at selected grid locations at the BORAX-I site. The boreholes were approximately 15 cm (6 in.) in diameter and 61 cm (24 in.) deep. The boreholes were scanned with a survey meter to rapidly identify boreholes with contamination above background. Eleven boreholes were identified for profiling with the sodium-iodide gamma-ray spectrometer. The measured concentrations of Cs-137 ranged from below the method detection limit to 3,700 ± 300 pCi/g at a depth of 15 cm (6 in.). The maximum concentration measured at the surface was 1,090 ± 80 pCi/g. The maximum concentration at any depth below 15 cm (6 in.) was 140 ± 10 pCi/g at a depth of 46 cm (18 in.). Five of the 11 boreholes showed the maximum activity to be approximately 15 cm (6 in.) below the surface, which is consistent with the 1978 survey results. Physical samples were also collected from selected depths in the boreholes. These samples were analyzed at the RML, and the results indicated that the Cs-137 concentrations differed from the values measured in the boreholes by as much as factors of 2 to 17. This demonstrates the particulate nature and heterogeneity of the contaminant distribution. The results from the borehole measurements are detailed in the *BORAX-I Radiation Survey* (Randolph, Coates, and Rowsell 1980) and summarized in Table A-2.

An extension of the June 1980 survey was conducted in November 1980. Using the same grid as in the June survey, a surface radiation survey was conducted at the BORAX-I site to determine the spatial distribution of surface contamination. A shielded pancake Geiger-Mueller probe and a digital rate meter were used to obtain count rate data for the survey grids. Figure A-2 shows the results of the surface survey with two general areas of elevated activity located to the southeast of the buried reactor.

Table A-2. Borehole survey summary data.

Location	Depth, inches	^{137}Cs Concentration, pCi/g	
		NaI Profile	Borehole RML Samples
N275 E100	Surface	1.4 ± 0.6	NC
	6	82 ± 6	28.3 ± 0.2
	11	ND	1.9 ± 0.1
N325 E100	Surface	0.9 ± 0.3	NC
	6	0.2 ± 0.5	NC
	17.5	1.4 ± 0.4	NC
N275 E125	Surface	100 ± 8	NC
	6	1060 ± 80	904 ± 1
	12	32 ± 3	NC
	15.5	25 ± 2	61.9 ± 0.4
N250 E25	Surface	ND	NC
	6	0.9 ± 0.9	NC
N365 E25	Surface	1090 ± 80	NC
	6	140 ± 10	NC
	11	30 ± 3	NC
N375 E125	Surface	7.8 ± 0.6	2.9 ± 0.1
	6	42 ± 3	0.86 ± 0.4
	12	ND	1.4 ± 0.1
N350 E175	Surface	12.5 ± 9	NC
	6	3700 ± 300	NC
N415 E175	Surface	24 ± 2	NC
	6	ND	NC
	12	26 ± 2	NC
	18	84 ± 6	NC
N425 E160	Surface	22 ± 2	NC
	6	9 ± 1	NC
	12	59 ± 4	NC
N420 E160	Surface	44 ± 3	NC
	6	340 ± 25	NC
	10.5	67 ± 5	NC
N300 E00	Surface	ND	NC

ND = Non-detect

NC = Not collected

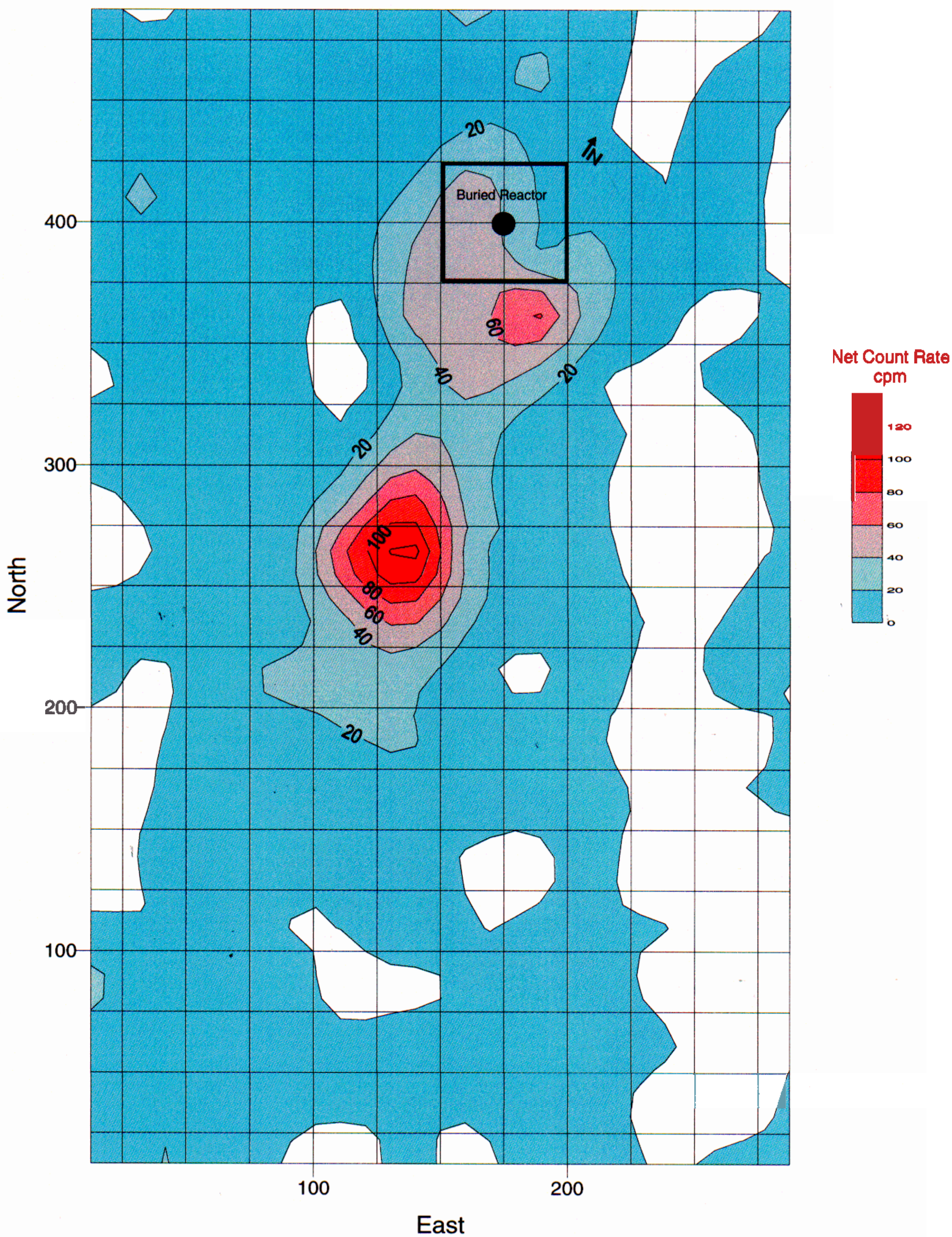

Figure A-2. Results of November 1980 radiological survey.

Radiological Survey: 1994

A radiological survey was conducted in November 1994 within the fenced area of the burial ground. All readings were taken at a height of 0.8 m (2.5 ft). No radioactivity above the local background of 0.1 mR/hr was detected.

BORAX-02 Remedial Action: 1995 and 1996

The BORAX-02 CERCLA site was remediated through the placement of a human intrusion cover (DOE-ID 1997). Prior to the remedial action, preconstruction sampling was conducted to define the areas requiring initial excavation and consolidation. The defined areas were then excavated and re-sampled to verify that remaining soils were below the final remedial action goals of 16.7 pCi/g for Cs-137, 10.8 pCi/g for Sr-90, and 13.2 pCi/g for U-235. A second excavation, followed by additional verification sampling, was performed where analytical results showed that radionuclide levels exceeded the action levels. The shaded areas in Figure A-3 show the locations where soils were excavated during the remedial action. The preconstruction sample concentrations ranged from below the method detection limit to maximums of 1,500 ± 200 pCi/g for Cs-137 and 15 ± 2 pCi/g for U-235 in the surface soils, and 91 ± 8 pCi/g for Cs-137 and 3 ± 0.3 pCi/g for U-235 from a depth of 0 to 15 cm (0 to 6 in.).

Post Remediation Annual Radiation Surveys: 1997 - 2001

Annual inspections have been conducted at the BORAX-1 burial ground since completion of the remedial action in 1997. The annual inspections were conducted in accordance with the requirements set forth in the Operable Units (OUs) 5-05 and 6-01 operations and maintenance plan (INEL 1997). Each annual inspection included visual inspection of the riprap barrier, with special attention given to subsidence and animal or human intrusion. Visual inspections of the fencing, signage, and permanent markers were also conducted. With the exception of a couple of anthills noted during each annual inspection, the engineered barriers and institutional controls appear to be effective in controlling intrusion and access to the sites. Revegetated areas were also inspected qualitatively for cover and encroachment of weeds and shrubs for and erosion. The revegetated areas are doing well, with insignificant encroachment of shrubs at the BORAX-I site, and there has been no significant erosion at the site. Radiological surveys at the BORAX-I site were conducted using a handheld micro-R (μR) rate meter held waist-high above the ground surface at points around the perimeters of the engineered barriers. The radiological surveys are conducted annually to verify that the engineered barriers remain effective in containing the radioactive material buried at the site. Table A-3 summarizes the annual radiological survey data and shows that radiation levels are consistent with background of 10 to 20 μR/hr.

As noted in Table A-3, the radiological survey in 1998 was a drive-over survey using the Global Positioning Radiometric Scanner (GPRS). The GPRS survey is discussed in Section 3.1.

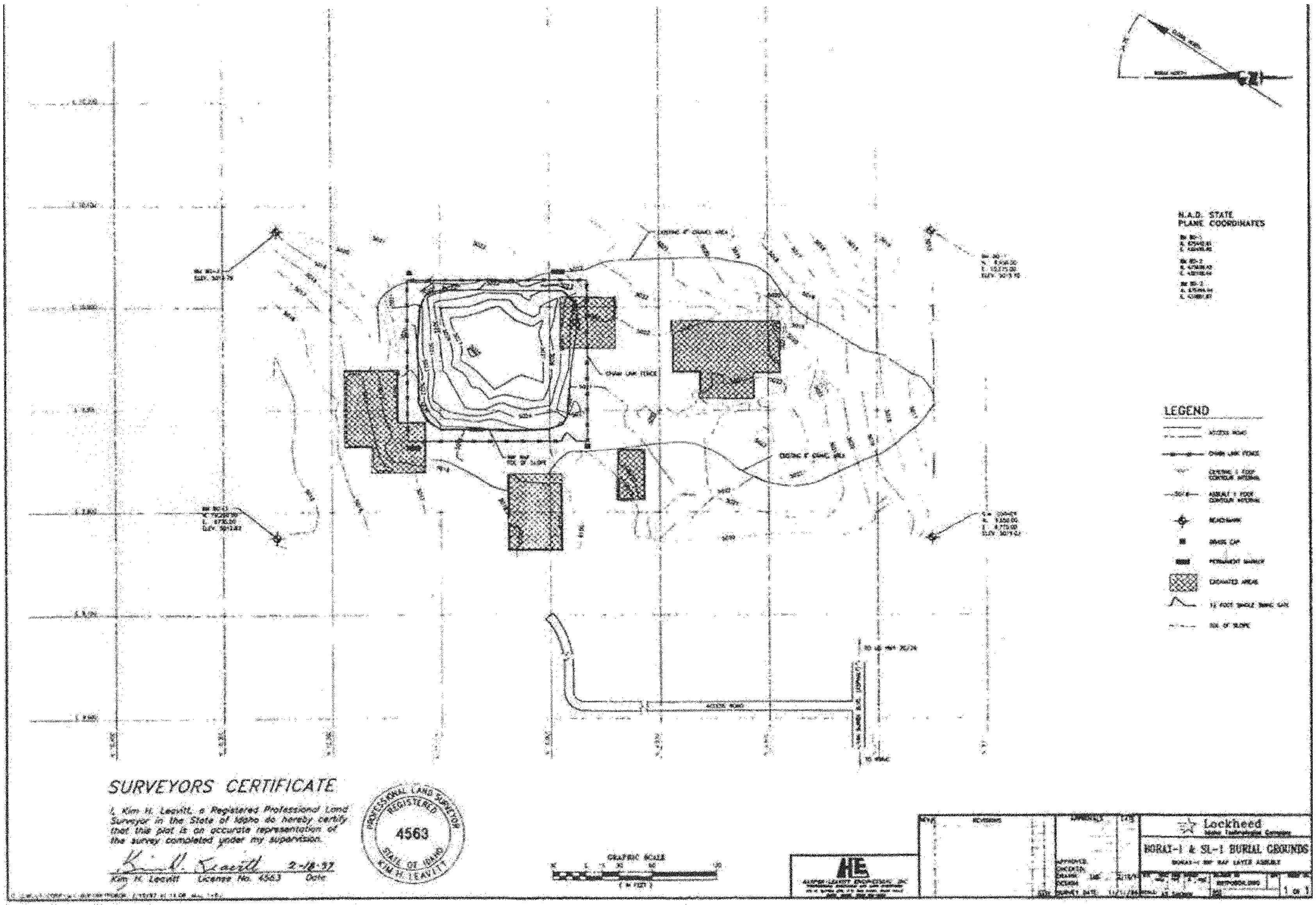

Figure A-3. BORAX-02 remedial action soil excavation areas.

Table A-3. BORAX-I summary of annual radiological survey data.

1998 Survey[a]	Average Dose Rate, μR/hr
BORAX-I	10.8
1999 Survey	
BORAX-I	10
2000 Survey	
BORAX-I	11.3
2001 Survey	
BORAX-I	10
Grand Average	
BORAX-I	10.5

a. The 1998 radiological survey included a survey with the INEEL GPRS system.

OU 10-04 Comprehensive Remedial Investigation/Feasibility Study Sampling: 2000

The BORAX-02 site was retained for evaluation in the OU 10-04 remedial investigation/feasibility study (RI/FS) (DOE-ID 2001) to support a cumulative human health risk assessment for the BORAX facility and to complete the assessment of the site's impact on ecological receptors. Researchers conducted a limited sampling and analysis effort in the summer of 2000 to address potential data gaps and to collect data in support of the ecological risk assessment for BORAX sites, including BORAX-02. A concern existed that small mammals burrowing under the riprap barrier could transport radionuclide contamination to the surface; therefore, small mammals, vegetation, and collocated surface soils were sampled for metals and radionuclide analyses. Figure A-4 shows the locations of the OU 10-04 comprehensive RI/FS sampling.

Cesium-137, Sr-90, and U-235 were detected in soil samples; however, the reported concentrations were below the record of decision (ROD) action levels in areas sampled outside the BORAX-02 engineered barrier during the 2000 sampling (DOE-ID 2001).

The contaminated area under review in this engineering design file was added to the BORAX-02 site in the OU 10-04 work plan. This area was assessed along with all other BORAX sites in Waste Area Group 6 in the OU 10-04 RI/FS. In the OU 10-04 ROD, the BORAX-02 site, including the area currently under assessment, will be placed under institutional controls.

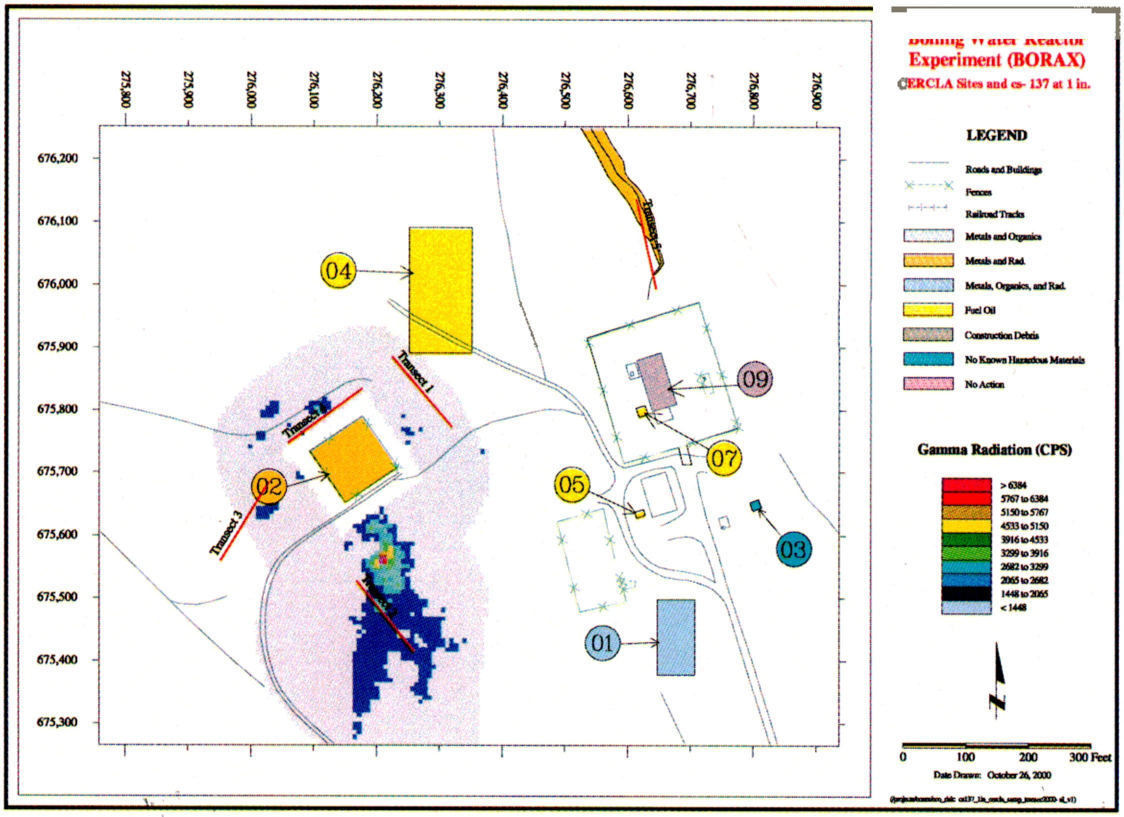

Figure A-4. OU 10-04 comprehensive RI/FS sampling, calendar year 2000.

References

DOE-ID, 1997, *Remedial Action Report Stationary Low-Power Reactor No. 1 and Boiling Water Reactor Experiment-1 Burial Grounds Engineered Barriers, Operable Units 5-05/6-01*, U.S. Department of Energy Idaho Operations Office, DOE/ID-10591, Rev. 0, October 1997.

DOE-ID, 2001, *Comprehensive Remedial Investigation/Feasibility Study for Waste Area Groups 6 and 10 Operable Unit 10-04*, U. S. Department of Energy Idaho Operations Office, DOE/ID-10807, Rev. 0, August 2001.

INEL, 1995, Remedial Investigation/Feasibility Study for Operable Units 5-05, and 6-01 (SL-1 and BORAX-I Burial Grounds), INEL-95/0027, Idaho National Engineering Laboratory, Revision 0, March 1995.

Randolph, P. D., R. A. Coates, and C. L. Rowsell, 1980, *BORAX-I Radiation Survey*, EG&G Internal Technical Report, RE-P-80-056.

Smith, D. L., 1980, *BORAX-I Radiological Characterization*, EG&G Internal Technical Report, PR-W-80-014.

Appendix B

MicroShield Models

Appendix B

MicroShield Models

MicroShield v5.05 (5.05-00340)
BBWI

Page : 1
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Run Date: April 25, 2002
Run Time: 11:03:02 AM
Duration : 00:00:02

File Ref:
Date: 4/25/02
By: J Giles
Checked:

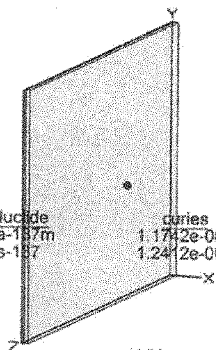
Case Title: BORAX I
Description: GPRS Field of View
Geometry: 13 - Rectangular Volume

Source Dimensions

Length	10.16 cm	4.0 in
Width	1.7e+3 cm	54 ft 2.4 in
Height	986.0 cm	32 ft 4.2 in

Dose Points

	X	Y	Z
# 1	125.4 cm 4 ft 1.4 in	493 cm 16 ft 2.1 in	826 cm 27 ft 1.2 in



Shields

Shield Name	Dimension	Material	Density
Source	16.549 m³	Common Soil	1.5
Shield 1	.152 m	Common Soil	1.5
Air Gap		Air	0.00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	μCi/cm³	Bq/cm³
Ba-137m	1.1742e-003	4.3444e+007	7.0950e-005	2.6252e+000
Cs-137	1.2412e-003	4.5924e+007	7.5000e-005	2.7750e+000

Buildup
The material reference is : Shield 1

Integration Parameters

X Direction	10
Y Direction	20
Z Direction	20

Results

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	8.994e+05	1.728e-16	4.842e-16	1.439e-18	4.033e-18
0.0322	1.659e+06	7.310e-16	2.094e-15	5.883e-18	1.685e-17
0.0364	6.039e+05	3.669e-13	1.344e-12	2.085e-15	7.639e-15
0.6616	3.909e+07	2.719e-01	1.610e+00	5.271e-04	3.122e-03
TOTALS:	4.225e+07	2.719e-01	1.610e+00	5.271e-04	3.122e-03

MicroShield v5.05 (5.05-00340)
BBWI

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Run Time: 11:01:26 AM
Duration : 00:00:02

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Date: 4/25/02
By: [illegible]
Checked: ______

Case Title: BORAX I
Description: GPRS Field of View
Geometry: 13 - Rectangular Volume

Source Dimensions

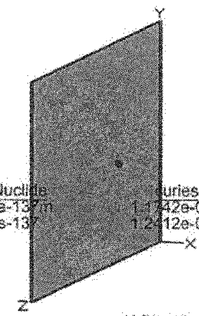
Length	10.16 cm	4.0 in
Width	1.7e+3 cm	54 ft 2.4 in
Height	986.0 cm	32 ft 4.2 in

Dose Points

	X	Y	Z
# 1	110.16 cm 3 ft 7.4 in	493 cm 16 ft 2.1 in	826 cm 27 ft 1.2 in

Shields

Shield Name	Dimension	Material	Density
Source	16.549 m³	Common Soil	1.5
Air Gap		Air	0.00122



Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	μCi/cm³	Bq/cm³
Ba-137m	1.1742e-003	4.3444e+007	7.0950e-005	2.6252e+000
Cs-137	1.2412e-003	4.5924e+007	7.5000e-005	2.7750e+000

Buildup
The material reference is : Source

Integration Parameters

X Direction	10
Y Direction	20
Z Direction	20

Results

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	8.994e+05	4.044e-04	5.379e-04	3.369e-06	4.481e-06
0.0322	1.659e+06	7.800e-04	1.044e-03	6.278e-06	8.404e-06
0.0364	6.039e+05	4.436e-04	6.450e-04	2.520e-06	3.665e-06
0.6616	3.909e+07	4.881e+00	9.405e+00	9.462e-03	1.823e-02
TOTALS:	4.225e+07	4.882e+00	9.408e+00	9.474e-03	1.825e-02